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Time Intervals between Accidents

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This study was undertaken in the hope of contributing to a clarification of the evidence on which the widely accepted theory of individual differences in accident liability is based. This evidence is incomplete. One of the principal facts included in it is the frequently-good fit of obtained accident distributions to the so-called unequal liabilities distribution [1] derived by Greenwood and Yule (4). This derivation includes the assumption of constancy of individual liability to accidents, i.e., the notion that accident liability of particular persons does not change with the passage of time or with the occurrence of accidents.

However, there are theoretical considerations which suggest that such an assumption is not likely to be exact. An accident can be expected to function at times as a traumatic experience and to disrupt subsequent behavior. It can also be expected to function as a punishment and, as such, to have one or another effect on the learning of the individual. There are some accident distributions which do not fit theoretical distributions based on assumptions of the constancy of accident liability (3). Very likely, in such cases accident proneness is affected by the accidents.

Even in the cases in which theoretical distributions based on the assumption of constant accident proneness do fit the data, the possibility of inconstant accident proneness cannot be excluded. It has been shown, e.g., by Irwin (6), that the same distribution which Greenwood and Yule derived in part from the assumption that accident liability varies from one individual to another but is constant for each individual, can also be derived from the assumption that there are no initial variations in accident liability, but that instead each accident increases the proneness of the individual by a constant amount. It can undoubtedly also be derived from an assumption of large initial differences in accident liability and decrease of accident liability with the occurrence of accidents.

Thus only tentative inferences may be drawn about the probable underlying distribution of accident liability from an obtained set of accident records, unless something is known about whether and how accidents occurring to people affect their accident liability. Not even the existence of initial differences in accident liability in the group may be inferred with certainty without such knowledge. In the absence of such knowledge, the assumption of unchanged liability after accidents was generally either implied (1) or explicitly made (10, 11) by workers in this field.

The factual evidence on the validity of the assumption of accident liability as unchanged by accidents is very scanty. Irwin has commented upon a few results on accident rates of groups of people in consecutive periods which were opposed to his hypothesis of accident proneness increasing with accidents. The accident rates did not tend to increase; the changes were slight, and, if anything, the rates tended to drop. A rather similar finding has been discussed by Kerrich (8). On the other hand, Horn has presented material on time-intervals between airplane accidents which suggested to him that accident susceptibility is temporarily increased by accidents. He recommended adjustment techniques for pilots following accidents. Thus the question may be of great practical importance to those interested in preventing accidents.

The Problem

It was thought that further research on time-intervals between accidents was desirable. Increasing accident proneness should show itself as a trend toward decreased time-intervals between accidents, while decreasing accident proneness should show the opposite trend. The problem of this paper was to discover whether trends towards such changes of time intervals do or do not occur.

However, there are methodological difficulties in such research. Thus it is not immediately obvious, how the interval before the first accident and the interval after the

[1] Or negative binomial distribution.

last accident during the arbitrary observation period should be treated, compared to the time intervals between accidents. This paper reports an attempt to deal with one set of data on time-intervals between accidents. It is hoped to provide examples of the type of information which can be obtained from the study of time-intervals, and to present some material relevant to the methodology in this field. The material is examined chiefly in relation to two possible theories: first, that accident proneness is constant for each individual; and, conversely, that proneness is increased with accidents.

The Data

The data examined were accident records of 178 taxi drivers, made available by Dr. E. Ghiselli, whose cooperation is appreciated. The period covered was one year. For each driver, the weeks in which accidents occurred were indicated. All drivers had worked for the company at least a year prior to the beginning of the observation period. Six drivers who resigned from their jobs during the observation period, or who were absent from work for eight or more weeks, were eliminated. Thus records of 172 drivers were included in this study.

The Mathematical Background

In order to discover what the time intervals before, between, and after the accidents indicate about the possible effects of accidents on accident liability, it is essential to compare them to the statistical expectancies based on the assumption that accidents are distributed over a time period completely at random. The hypothesis of random distribution of points within an interval has been previously studied by Whitworth (13), Greenwood (2), Moran (12), and Maguire, Pearson and Wynn (9). It assumes that each accident is independent of all other accidents and that its occurrence is equally probable at all times during the period. However, this is assumed only if each accident is viewed as a separate entity, defined in terms of what happens (e.g., sideswiping a particular telephone pole) rather than in terms of the position of the accidents relative to each other. Sideswiping the telephone pole is more likely to be the first accident if it happens early in the observation period than if it happens late; and so with other types of accidents. The probability that a particular accident is the first one during the observation period is proportionate to the probability that no other accident has yet taken place. This probability decreases with the passage of time.

If n accidents have happened to an individual during a time interval of unit duration, the probability of the first accident happening at time x decreases in proportion with $(1-x)^{n-1}$ as x increases. The probability function of the first accident within a total time interval of unit length is given by the expression $n(1-x)^{n-1}$. The probability of the second accident at time x involves first, that one accident must have taken place already, and second, that no other accident shall have happened yet. Its formula is $n(n-1)x(1-x)^{n-2}$, and similar expressions may be derived for the probabilities of the times of the other accidents.

Probability functions can generally be used for the computation of theoretical means and standard deviations. Such computations indicate that, in terms of the null hypothesis, statistical expectancies for the mean time-intervals from the beginning of the observation period to the first accident; from the first to the second; and so on, including the time-interval between the last accident and the end of the observation period are the same. Similarly, the expectancies of the variances of the time-intervals are also identical. In studying the possible effects of accidents on accident liability, the periods before the first accident and after the last accident may be treated in the same manner as the intervals between accidents.

Results

Of the 172 drivers included in the computation, 60 had no recorded accidents and 112 drivers had one or more accidents, ranging up to 25. The accident distribution was very different from the theoretical distribution which results from the assumptions of equal and constant accident liability. In an equal liability or so-called Poissonian distribution, the variance of accidents is equal to the mean. In the Ghiselli data, it is about

six times as large as the mean. The distribution seems to be capable of being explained in terms of the hypothesis of large stable differences in accident liability. On the other hand, in accordance with the considerations mentioned earlier, it also can be explained in terms of other assumptions, e.g., that of linear increase of accident liability with accidents.

What do the time-intervals indicate? They were first examined separately for groups of drivers with different accident records.

A total of 45 drivers had one accident each. The theoretical expectancy for the position of the mean time of a single accident is 26 weeks. The obtained mean was 21.9 weeks. The critical ratio was 1.99,[2] which is significant at the .05 level. It should be noted that this suggestive difference is in the opposite direction from the one which would be expected if accident liability increased with accidents. The question was not investigated whether this result was due to the fact that accident liability decreased with the first accident in this group, or whether it was produced by seasonal fluctuations.

In the two-accident case, the situation was somewhat similar. The mean durations of the three time-intervals (up to the first accident, between the first and second accidents, and from the second accident until the end of the observation period) were 13.1; 15.6; and 23.2, respectively. The theoretical expectancy is 17.33, with a standard error of 3.06 weeks. The differences between the time-intervals are again suggestive of a decrease in accident liability after accidents, but the result does not seem to be statistically significant.

The situation was somewhat different in the cases which had three, four, and five accidents. Here the first and last time-intervals were longer than the time-intervals between accidents, but this finding was again of doubtful statistical significance. Groups with more than five accidents were too small for detailed presentation.

The significant fact which emerges from the examination of the mean time-intervals of groups of drivers, classified on the basis of number of accidents, is that there was no consistent trend toward a decrease of time-intervals with repeated accidents. Table 1 presents the data.

In the preceding discussion, separate comparisons of time intervals were made within each group of drivers with a particular number of accidents. These groups were for the most part very small. Therefore the data were also treated in another way, in terms of cumulative groups. For all drivers who had one or more accidents, the mean time interval before their first (or only) accident was ascertained. The mean time interval before the second accident was ascertained for all drivers with two or more accidents, and for the same group the mean time interval before the first time accident was also computed. Similarly, the mean time intervals before the third accident and before the first accident were determined for the group with three or more accidents, and so on.

The results of these computations are presented in Table 2, the first column of figures giving the mean times between the consecutive accidents and the second column giving the mean times before the first accidents of the same people, and the third column presenting the differences. It should be noted that according to both hypotheses considered in this paper, the figures in the first column should tend to decrease as one proceeds down the table.

According to the theory of individual differences in accident proneness, the same decrease is expected in the second column; this is to be expected because the bottom of the table deals with drivers who had repeated accidents, because repeated accidents are apt to be indicative of high accident proneness, and because high accident proneness is apt to result in short time intervals both before the first accident and between the later accidents. According to the theory of increased proneness following accidents the decrease should be much more pronounced in the first column than in the second one,[3] and the differences in the third column should tend to be negative and to increase in absolute amount.

[2] The critical ratio rather than the t-ratio was used because a theoretical standard deviation could be and was utilized.

[3] There are two reasons for expecting some downward trend in these figures according to the behavior disruption theory. First, there are selective factors: people who had the first accident early "by chance"

Table 1

Mean Times * Before the First Accident, Between Accidents, and After the Last Accident

One-accident group	(n = 45):	21.9; 30.1
Two-accident group	(n = 16):	13.1; 15.7; 23.2
Three-accident group	(n = 13):	16.1; 9.6; 12.9; 13.4
Four-accident group	(n = 13):	14.0; 8.6; 5.5; 5.6; 18.3
Five-accident group	(n = 4):	9.7; 6.0; 5.5; 7.8; 8.2; 14.8
Six-accident group	(n = 5):	5.9; 4.8; 6.8; 9.2; 10.6; 10.0; 4.7
Seven-accident group	(n = 3):	2.5; 10.0; 5.3; 5.7; 9.0; 7.0; 6.0; 6.5
Eight-accident group	(n = 2):	1.0; 2.0; 6.5; 7.5; 5.5; 2.0; 2.5; 11.5; 13.5
Nine-accident group	(n = 3):	2.2; 2.7; 9.7; 6.7; 3.0; 3.3; 1.3; 8.0; 5.0; 10.2
Eleven-accident group	(n = 2):	8.5; 2.5; 1.5; 2.5; 1.5; 3.5; 6.0; 4.5; 8.5; 2.5; 6.0; 5.5
Twelve-accident group	(n = 1):	2.5; 1; 6; 4; 6; 2; 1; 2; 6; 1; 2; 4; 14.5
Thirteen-accident group	(n = 1):	1.5; 1; 5; 1; 2; 1; 1; 8; 2; 13; 1; 11; 4; 0.5
Fifteen-accident group	(n = 1):	1.5; 1; 1; 3; 3; 2; 3; 6; 5; 1; 4; 5; 3; 10; 2; 1.5
Sixteen-accident group	(n = 1):	2.5; 7; 2; 1; 1; 1; 5; 6; 3; 1; 5; 2; 6; 1; 2; 3; 3.5
Eighteen-accident group	(n = 1):	0.5; 2; 1; 12; 1; 1; 3; 1; 1; 1; 1; 1; 5; 1; 2; 1; 3; 10; 4.5
Twenty-five–accident group	(n = 1):	3.5; 1; 1; 1; 2; 1; 1; 5; 2; 1; 1; 1; 6; 1; 6; 1; 1; 1; 7; 1; 1; 3; 1; 1; 1; 0.5

* In computing the mean times it was assumed that the accidents occurred in the middle of the week.

The increase of the magnitude of the differences should occur because the accidents intervening between the first accident and the later ones are assumed to increase their accident proneness. This factor would be assumed to produce a marked decrease in the figures of the first column; it would be assumed to be lacking in the case of the figures in the second column, in which only a weaker downward trend would be expected.

There are a number of statistical procedures by means of which the agreement of the two hypotheses with the data could be tested. However, their presentation would have required much space, mainly because of two difficulties: the groups of drivers overlap, so that the figures in the second column are not independent, and the theoretical distributions of the time intervals are not normal. It was not thought that the expected gain from the treatment of the data embodying these considerations was likely to justify the added space. Therefore the material is treated in terms of a simple inspection of the table.

The expected tendency towards decreasing time intervals between the higher numbered accidents is present. As the incidence of accidents rises, the time interval before the first accident also tends to grow shorter, to about the same extent. As one reads down the table, there is no tendency toward larger negative values of differences. There are some fluctuations in the values of these differences, but these fluctuations are not large, do not suggest an intelligible pattern, and according to tentative computations do not seem to be statistically significant.

have more time left in which they may have additional accidents; second: the drivers in this study were not new and may have developed differences in accident proneness as a result of accidents occurring before the observation period.

Discussion

These results are clearly not in favor of the hypothesis of increased accident susceptibility with accidents. For this set of data the theory of proneness, varying from person and reasonably-constant for each person appears to be more appropriate.

This conclusion requires qualifications. It should be noted that certain factors were not taken into consideration in this study. The possibility of seasonal fluctuations in accident rates was one such factor. Another factor not considered had to do with the different distances driven by the different drivers. Both of these factors are likely to have functioned as sources of variation in the accident rates, and taking them into account should have given a somewhat better test of the hypothesis of constant accident proneness of individuals.

Table 2
Comparison of Mean Time Intervals in Weeks Before First Accident and Before Later Accidents

	Mean Time Interval	Mean Time Interval of the Same Drivers Before First Accident	Difference
Before 1st accident (112 drivers)	15.1		
Between 1st & 2nd (67 drivers)	8.9	10.7	−1.8
Between 2nd & 3rd (51 drivers)	7.3	9.9	−2.6
Between 3rd & 4th (38 drivers)	6.0	7.8	−1.8
Between 4th & 5th (25 drivers)	6.0	4.5	1.5
Between 5th & 6th (21 drivers)	4.8	3.5	1.3
Between 6th & 7th (16 drivers)	3.3	2.8	0.5
Between 7th & 8th (13 drivers)	6.5	2.9	3.6
Between 8th & 9th (11 drivers)	4.6	3.2	1.4
Between 9th & 10th (8 drivers)	3.2	3.6	−0.4
Between 10th & 11th (8 drivers)	3.2	3.6	−0.4
Between 11th & 12th (6 drivers)	4.0	2.0	2.0
Between 12th & 13th (5 drivers)	4.8	1.9	2.9
Between 13th & 14th (4 drivers)	3.2	2.0	1.2
Between 14th & 15th (4 drivers)	3.0	2.0	1.0
Between 15th & 16th (3 drivers)	1.7	2.2	−0.5
Between 16th & 17th (2 drivers)	2.0	2.0	0.0
Between 17th & 18th (2 drivers)	5.5	2.0	3.5
Between 18th & 19th, 19th & 20th, etc. (1 driver)	7, 1, 1, 3, 1, 1, 1	3.5	3.5, −2.5, −2.5, −0.5, −2.5, −2.5, −2.5

However, this hypothesis is probably only an approximation which is not applicable to all individuals and groups. The records of a few drivers suggest temporary fluctuations of accident proneness with some individuals. Temporary increases in accident proneness

may well be due to periods of emotional stress.

However, there is need to investigate the statistical significance of such apparent fluctuations in accident proneness or liability. Maguire, Pearson and Wynn (9), Greenwood (2), and Irwin (7) have pointed out certain difficulties in determining the statistical significance of departures of sequences of time intervals from randomness, and it is not entirely clear to this writer whether the problem has been solved.

The apparent lack of systematic effects of accidents on accident rates found in this study need not hold for all groups. It may have partly resulted from the fact that all drivers had worked for the company at least a year before the observation period. Considerations based on the psychology of learning suggest that accident proneness might be less constant with inexperienced workers. Research on time-intervals between accidents for inexperienced workers is worth attempting.

Our finding is not in agreement with Horn's conclusion that accident susceptibility is temporarily increased by accidents. This disagreement with Horn's conclusion may represent a difference between different kinds of accidents, since his data dealt with airplane accidents and ours with accidents to taxi-drivers. On the other hand, the discrepancy may be due to different statistical treatments. Possibly a statistical artifact was involved in his conclusions. Horn's tables showed a relative preponderance of short time intervals over longer ones between consecutive accidents. However, he was apparently not aware of the nature of the distribution of the time intervals between events distributed at random within a period of time, and his tables do not indicate whether or not his results differed from chance expectancy. The matter calls for further investigation.

Summary

Much of the evidence in favor of the commonly accepted hypothesis of indivdual differences in accident proneness is only valid if one assumes that accident proneness of individuals is not affected by accidents in which they are involved. The validity of this assumption is investigated in terms of a study of time intervals between consecutive accidents of a number of taxi-drivers. Some features of the relevant mathematical theory of the random distribution of events in time are reviewed. The findings pertaining to the time intervals between accidents suggest, that, for the group studied, the customary assumption of unchanged accident proneness following accidents is approximately true.

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